EARLY DEGRADATION OF PV MODULES AND GUARANTY CONDITIONS

M.A. Munoz, M.C. Alonso-García, F. Chenlo
Photovoltaic Laboratory, Renewable Energy, CIEMAT
Avda. Complutense, 22; 28040 Madrid, Spain
miguelangel.munoz@ciemat.es Phone: +34 913466497; Fax: +34 913466037

ABSTRACT: CIEMAT PVLabDER has largely increased its demand on testing and characterizing PV plants, according to the fast growth of PV installed capacity in Spain. One of the topics in which manufacturers, promoters, and owners of the plants are more interested in, is the possible degradation of PV modules and its relationship to guarantee contracts, as it is related to subsidies. This paper presents some findings in campaigns of PV plants evaluation carried out during last years. This evaluation usually consists of visual inspection, I-V curve measurement in the fields (the whole plant or selected areas), thermal evaluation by IR imaging, and, in some cases, measurement of the I-V characteristic and thermal behaviour of selected modules in the plant, chosen by the laboratory. It must be noticed that new defects that grow when the module is into operation may appear in modules initially free of them (named as hidden manufacturing defects). Usually some of these hidden defects that only appear in normal operation are not detected in reliability tests (EN61215 or EN 61646) [4][5] due to the different operational conditions of the module in the standard tests and in the field (serial-parallel connection of many PV modules, power inverter influence, over voltage on wires, etc.)

Keywords: PV Module, Degradation, Defects

1. INTRODUCTION

Photovoltaic market in Spain has grown rapidly in past years. It has passed from 250 MW to more than 2.500 MW installed only in last year.
This increase led to the fact that more than twelve million PV modules were installed. And also that more than eight hundred million of solar cells were necessary to manufacture them. It is quite clear that in such huge population sometimes we find PV modules with problems. Besides this, when a problem appears, affects to a higher number of modules.

Problems not always were detected during the manufacturing of the PV modules or the silicon but they can appear later when the modules are already installed and working in the plant.

At the moment this fast increase has been calmed due to the new regulation that allows the installation of 500 MW/year in the next years, but a demand for testing laboratories to analyse early degradation and hidden defects studies in PV modules and plants has arisen. This topic is related to guaranty contracts, and manufacturers, promoters and owners are uncertain whether these defects or early degradations should cause the rejection and reposition of PV modules. This paper shows different kinds of PV module defects and analyses its effects over peak power of the module.

Other questions are mentioned, such as IR characterization analysis (taking into account three possibilities: maximum power point, short circuit condition and middle range operation), the consideration of visual defects as only cosmetic or a serious manufacturing defect, etc.

Among the most common visible effects we can outline:
- Yellowing
- Delaminations
- Bubbles
- Cracks in the cells
- Defects in the antirreflexive coating
- Burnt cells

These problems found in plants that are in operation for a not too long period of time, make necessary the definition of certain criteria in order to determine which can be consider a major defect that implies the replacement of a module under guaranty. To do that, the categorization of defect types and the evolution of them with time is required.

2. ANALYSIS PROCEDURE.

The analysis of the defects listed in the previous section was performed by means of different tests. First, the I-V characteristic curve was measured in order to detect power losses that could be related to cell changes. I-V curve measurement was performed according to IEC 60904-1[1][2], what permits to obtain main parameters, Isc, Voc, Im, Vm Pm and FF in Standard Test Conditions (STC):

- Irradiance: 1000 W/m²
- Cell temperature: 25°C
- Spectral distribution: AM1.5G (according to IEC 60904-3)
- Normal incidence

Measurements were performed indoors, with a flash pulsed class AAA IEC 60904-3 [3] solar simulator (10 ms pulse). All measurements were done at temperature and irradiance conditions very closed to STC (1000 ± 5 W/m2 and 25 ± 2° C). Short circuit current and open circuit voltage were extrapolated to 1000 W/m² and 25°C using α and β coefficients respectively. The influence of these corrections is minor, due to the small difference between measured and standard conditions.

Besides, infrared imaging and electroluminescence tests were performed in some modules.

IR characterisations can be performed in different conditions, being the most significant, short circuit, a working point close to maximum power and forward bias of the module at a current similar to short circuit current. Worst case with respect to temperature increase and hot sport occurrence is the module in short circuit conditions. This can be achieved in laboratory but not in the plant, unless it is disconnected and the sample taken out of the circuit. Furthermore, temperature differences in module surface are different depending on the operation point of the module. Modules that in short circuit conditions could show large temperature increases in one of their cells may not increase their temperature in normal operation conditions. On the other hand, there are other local effects that may affect the thermal behaviour of the module working in the plant, that are not present in the hot-spot tests carried out in laboratories.

Electroluminescence tests were performed in the laboratory, applying a forward voltage slightly higher than open circuit voltage to get a similar current to short circuit current. In these conditions, the module emits light in the wavelengths where it is sensitive. An 850nm filter was used, with acquisition times from 5 to 30 s. These conditions were chosen to minimize noise and increase sensitivity. Darker areas in the images correspond to less active areas, suggesting defective regions. Besides, it is easy to detect with this method contact finger breakages, shunts and microcracks. [7][8]

3. RESULTS AND DISCUSSION.

Following are presented and commented main defects found.

3.1. Yellowing

Consist of a tedlar colour change or a colour change in the material in the back side of the module from white to yellow. With the tests performed it can not be asses the influence of this defect in the power losses of the module. Despite this, the yellowing could be a problem if it would start a lack of adherence between the tedlar and the module, causing water penetration inside the module.

In some PV modules, yellowing appear in some areas but not in adjacent areas with a different tedlar of a different origin or characteristics. This should mean that yellowing appears in tedlar instead in the adherent element (usually EVA).

Figure 1 shows an example of how the yellowing effect is due to a change in the colour of the tedlar instead to changes in EVA.

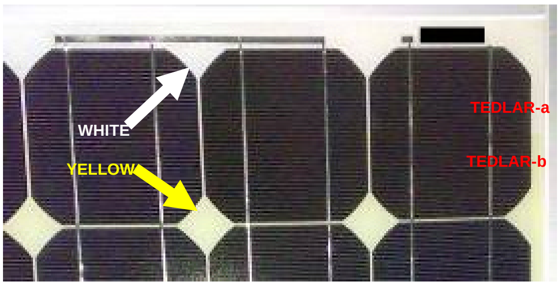

Figure 1.- Yellowing over an area of a PV module.

3.2. Delamination

It consists of the tedlar adherence loss with the subsequent unstuck. It is a major problem because it can cause water penetration inside the module structure. It is more severe if it occurs in the borders of the module because, apart of the power losses, it causes electric risk for the module and the installation.

3.3. Bubbles

It is a type of delamination combining the lack of adherence between the tedlar and the back side of the module with the blowing of the areas where this adherence has been lost. These bubbles make more difficult the heat dissipation of the cells in these areas, overheating them with the subsequent reduction of cell lifetime.

On Figure 2 we can see an example of a module with many bubbles in the back side. Usually they appear in the centre of a cell, maybe due to a different adherence of the cell.

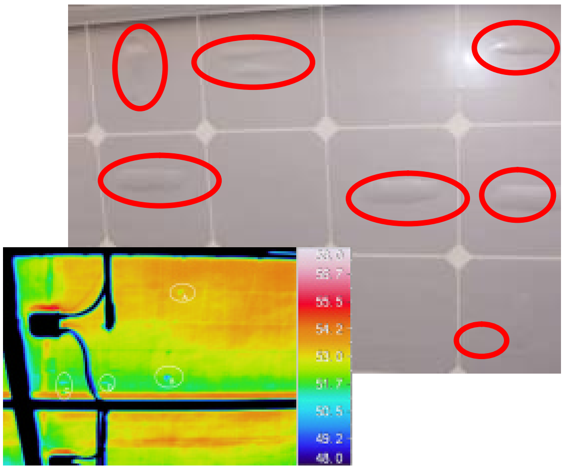

Figure 2.- Bubbles in the back side of a PV module.

On Figure 3 we can see how bubbles can also appear in the front side of a PV module, between the glass and the silicon cells. In this case it is a detachment between part of the cell and the glass. The influence in the front side of the module is minor in this case, because cells are more rigid than tedlar. Air or gas is again accumulated in the bubbles, probably due to some chemical reaction. Here, apart from heating effects it is added the fact that light incidence in the cell can be reduced.

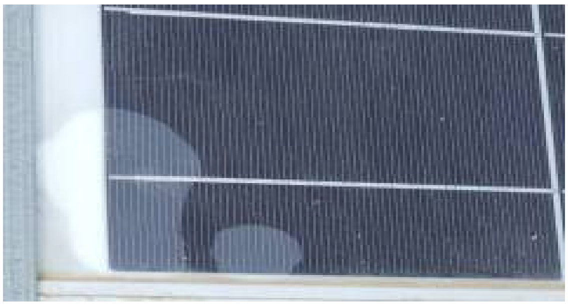

Figure 3.- Bubbles in the front side of a PV module.

3.4. Cracks in cells

The market of silicon solar cells has changed the thickness of cells in few years from 300µm to less than 200µm.

This thickness reduction makes the cells more fragile and susceptible to breakages during its manipulation, module lamination or storage.

Microcracks consist of small cell cracks usually not visible, that may affect both sides of the cell. They produce a loss in cell consistence and a possible carrier recombination path. Sometimes, different colour lines can be appreciated in the cell, although the cracks are not visible at a sight. When modules with these different coloured lines are tested by electroluminescence, there is good accordance between these lines and the microcracks observed by EL. Microcracks areas are darker in EL because either they do not produce light emission, or this emission is lower. In some cases the cracks isolate parts of the cell avoiding current generation as we can see in Figure 4.

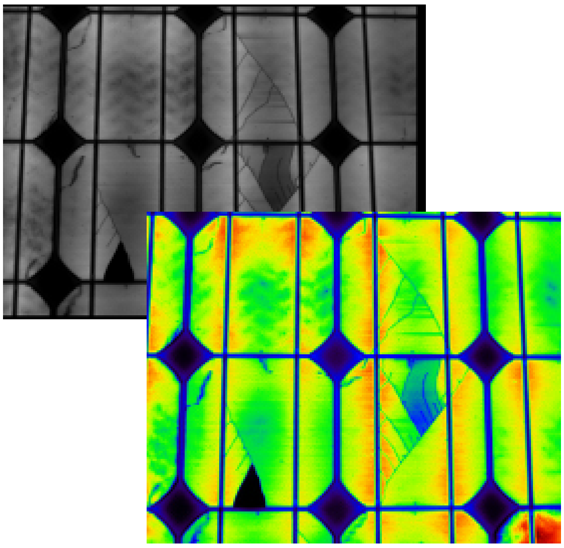

Figure 4.- Cracks in cells. B&W image an simulated colour image.

The IR characterisation of these modules both in short circuit conditions and in the operation point did not show a particular temperature increase in the damaged areas. Forward bias IR characterisation showed some temperature distributions with the same shape as those found by EL, but temperature differences were rather small (a few degrees, sometimes lower, others higher, than the adjacent areas) making difficult the interpretation of temperature patterns.

3.5. Defects on antireflexive layer

The layer that covers each cell of the module suffers a change that induces a change in the colouring (Figure 5). The antireflection properties may suffer changes as well and in this case the light that achieves the cells may be lower than expected. Nonetheless, this colour change should not cause a decrease in the wavelengths that the cells use, affecting only to visible Light.

IR characterisation of these modules in different conditions did not show any particular effect that could be associated with the changes in the colour of the AR layer.

A follow up of the affected modules should be done in order to detect if this defect lead to another that could be severe.

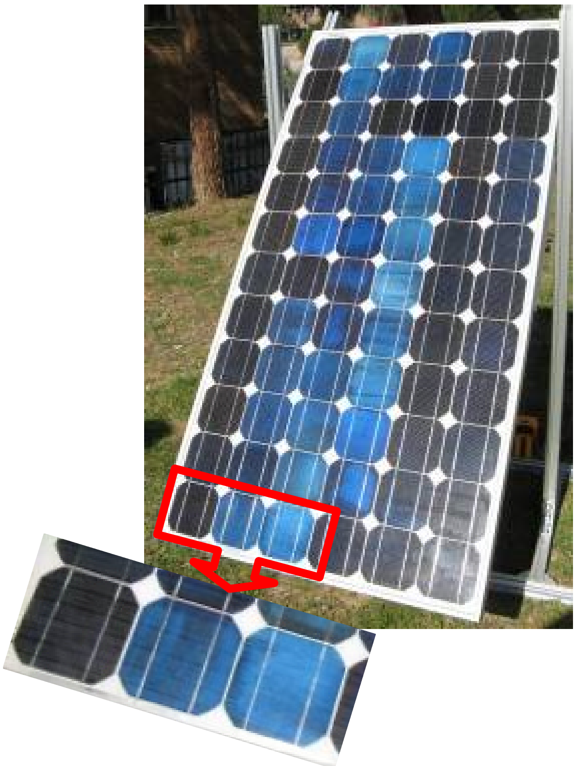

Figure 5.- Decolouring of cells due to a change in antireflexive coat.

3.6. Other defects.

- Lines and blemishes that appear in the cells.

Lines sometimes are indicating a crack in the cell. Probably this crack leads to a chemical reaction or a migration that affects the antireflexive layer and the line appears (Figure 6).

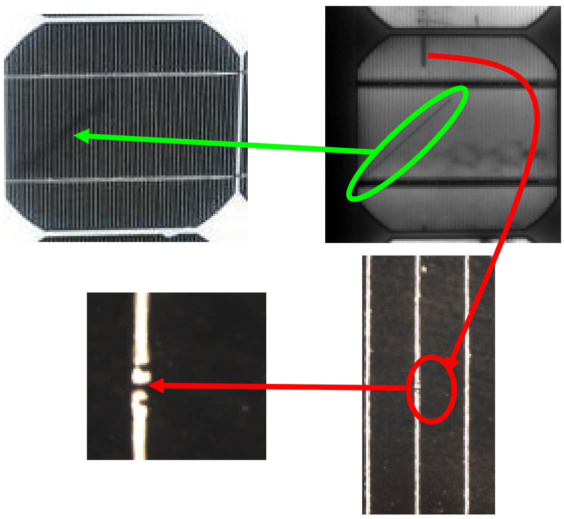

Figure 6.- Two defects detected with EL image. One of them not visible at a sight.

- Detachment of the frame.

It sometimes appears after the PV module has been installed. It could be due to an incorrect installation where the module supports an excessive weight or because the adherence between the frame and the glass is not strong enough. We can see an example of this in **Figure 7**.

Figure 7.- Detachment of the frame.

- Power losses higher than guaranteed.

Manufacturers usually give a tolerance for module nominal power in standard test conditions [6]. They also guarantee power delivered by the module within a range for a certain time (usually 10% during 10 or 15 years), increasing the time in some cases to 20 or 25 years with 80% of the nominal power. Nevertheless, power losses higher than the ones indicated in guarantee contracts have been found in some cases when measuring modules taken out of the plants.

In some cases, a significant degradation is reported. After obtaining a I-V curve of a module where clearly can be seen that a string has bad cells a EL image can be taken to confirm this situation (Figure 8).

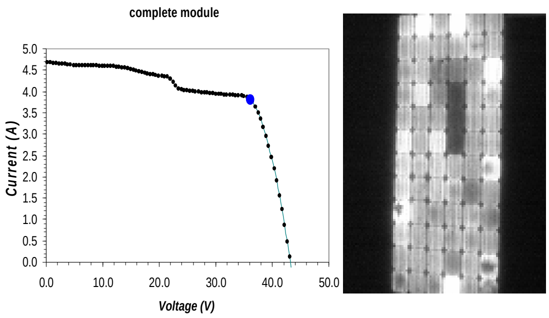

Figure 8.- Supposed string with bad cells.

Besides this, an I-V curve analysis string by string can be performed. In this case, the I-V curve can be obtained from the leads of diodes after opening the connections box. Figure 9 shows the same module where the I-V curve was obtained from each string.

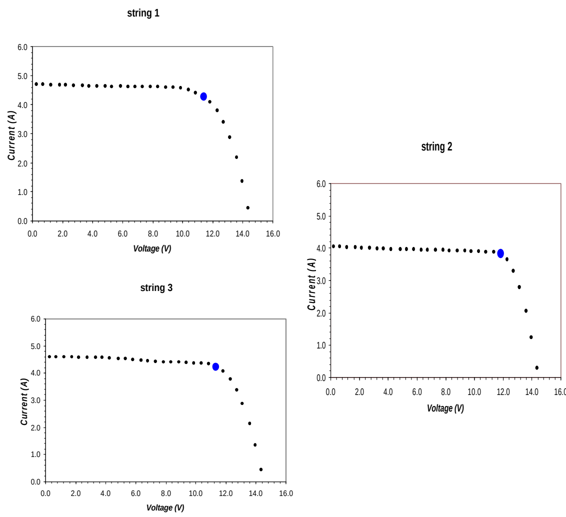

Figure 9.- I-V analysis string by string.

The analysis show how central string (string 2) has worse cells than the other ones (current is lower) and it affects the complete module.

These power losses can be only detected by measuring a representative sample of the total population of the solar plant periodically.

4. CONCLUSIONS.

An initial follow-up of the modules of a plant should be done in order to be able to detect early degradations in modules during the initial guaranty period. To do this, the first inspection should be a visual inspection looking for defects as mentioned like bubbles, delamination, decolouring or any strange figure that could appear over the cells and that could indicate an initiating defect.

After this, a sample of these modules should be sent to a laboratory in order to determine if it is a real defect and could lead to a claim to the manufacturer of the modules.

Cracks over the cells could appear not only during the lamination process but during the storage or the installation of the module. These cracks could be a problem in the future.

5. REFERENCES.

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